

Microfacies Analysis and Depositional Environment of the Ibrahim, Azkand and Anah Formations in Selected Oil Fields of Northern Iraq.

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Abstract

This study focuses on the analysis of the Ibrahim, Azkand, and Anah formations within three major oil fields (X, Y, and Z) located in the Low Folded Zone of Iraq. Integrated microfacies and stratigraphic interpretations reveal a regressive depositional succession spanning the late Oligocene to early Miocene. The lower and middle intervals of the Ibrahim Formation are characterized by microfacies SMF-3, deposited in the deeper sector of Zone FZ-3, interpreted as a toe-of-slope environment under low-energy, distal slope conditions. The upper part of the Ibrahim Formation is dominated by microfacies SMF-4, reflecting a distinct shallowing into a shallower platform setting within the same zone (FZ-3) and marking the onset of a marine regression. The overlying Azkand Formation records continued platform progradation, with its lower section represented by microfacies SMF-5, indicative of an upper slope environment (Zone FZ-4), and its upper part is defined by microfacies SMF-7, characteristic of a high-energy reefal system (Zone FZ-5). The Anah Formation begins with microfacies SMF-8 in its lower part, deposited in an open marine platform interior (Zone FZ-7), and evolves upward into microfacies SMF-18 in the middle and upper sections, representing a restricted platform interior (Zone FZ-8). Gamma-ray logs, which show a decreasing radioactivity trend and confirm a shallowing-upward trend of the depositional environment, corroborate this regressive succession. The depocenter lies near field Z, while field Y occupies a basinal position. The paleo-shoreline extended northwest-southeast across Iraq, aligned through fields X and Z, delineating a rimmed carbonate platform with implications for reservoir characterization and exploration.

Keywords:

Depositional Environment, Microfacies, Oligocene, Kirkuk group, Iraq.

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1. Introduction

The Ibrahim, Azkand, and Anah formations are distinguished by their substantial oil production capabilities across several fields, establishing them as critical hydrocarbon reservoirs with outstanding petrophysical features (Jassim and Goff, 2006). Although the studied formations have been the subject of numerous investigations, most previous studies have been localized and focused on individual units or isolated outcrops. This study offers a unique regional synthesis by integrating microfacies and well-log data from the Anah, Azkand, and Ibrahim formations across multiple

oil fields, demonstrating their deposition within a single and laterally continuous basin during the same geological interval. Unlike previous localized studies confined to individual formations or single fields, this cross-field, multi-formation approach reveals consistent basin-scale facies trends and paleoenvironmental patterns essential for reliable reservoir prediction. The Anah and Azkand formations, in particular, exhibit strong reservoir properties (porosity, permeability, and lithological uniformity), yet their lateral continuity and spatial quality distribution across fields remain poorly documented. By systematically correlating these units across the basin and linking facies to

depositional settings, this research provides a predictive sedimentological framework to target undrilled prospects and optimize field development, directly enhancing exploration efficiency and reducing drilling uncertainty.

The Ibrahim, Azkand, and Anah formations are deposited during the late Oligocene age as a third depositional cycle (Bellen et al., 1959) or second cycle according to Jassim and Goff (2006), while others consider them to be deposits of early Miocene age (Ighwan and Al-Rahman, 2009). Ditmar (1971) revised the three-fold classification of the Oligocene sedimentary cycle, redefining it into two distinct subcycles, as cited by Al-Shareeda et al. (2025). The Oligocene sequence in Iraq consists of nine formations called the Kirkuk Group, which is divided into the early, middle, and late Oligocene complex reefal system (back-reef, reef, and fore-reef). The late Oligocene includes the Anah, Azkand, and Ibrahim formations (Al-Hashimi and Amer, 1986).

Numerous research studies have addressed the depositional environments of the Ibrahim, Azkand, and Anah formations across Iraq. Karim et al. (2012) studied Oligocene carbonate succession exposed southeast of Derbandikhan and northeast of Kalar within the Sharwaldir anticline. The succession includes the Baba and Anah formations and a transitional zone between them, with depositional environments interpreted as fore-reef (lower), reef-crest (middle), and back-reef (upper). Lawa and Ghafur (2015) documented a progressive facies transition within the Oligocene Kirkuk Group in the Kurdistan Foreland Basin from inner ramp to outer ramp and finally to deep and planktonic-rich basinal deposits reflecting a deepening-upward depositional trend. Ghafor and Ahmad (2019) interpreted the Anah Formation in the Sangaw area (Sulaimaniyah) as deposited in a middle to inner carbonate ramp setting (40–80 m depth) under tropical and oligotrophic conditions. Abdulrahman and Awadh (2021) identified a deep shelf to lower slope environment for the Ibrahim Formation in Zurbatiya with evidence of significant meteoric and burial diagenesis. Mahdi et al. (2022) recognized six microfacies in the Khabaz Field reflecting a transition from back-reef to slope environments within the Azkand and Anah formations. Ghafor et al. (2023) confirmed a shallow euphotic and subtropical ramp setting for the Anah Formation in the Darzila section. Mohammed and Aljibouri (2023) assigned these

formations in the Anah area to distinct reef, fore-reef, and back-reef paleoenvironments. Abood and Al-Zaidy (2024) documented six facies' associations in the Fallujah and Melh-Tharthar oilfields, indicating a prograding carbonate platform system. Most recently, Majeed et al. (2025) distinguished the Anah, Azkand, Ibrahim, and Palani formations in the Khabaz and Kirkuk fields through detailed microfacies analysis, refining their environmental and stratigraphic correlations.

2. Location

The study area is located in the southern and southeastern parts of the Kirkuk oil field, covering wells X1 and X2 in Field X, Y in Field Y, and Z in Field Z. The study area includes three important oilfields (X, Y, and Z). They are sited in northeastern Iraq within the Unstable Shelf in the low Folded Zone (Fouad, 2010). Field X is a subsurface and asymmetrical anticline located approximately 12 km southwest of Kirkuk City, extending in a northwest–southeast direction. The structure measures about 10 km in length and 5 km in width. Field Y is one of the major producing fields in northern Iraq. It consists of a long, elongated, and asymmetrical anticline trending northwest–southeast and situated to the east of Kirkuk. The field extends for nearly 30 km in length and 4.5 km in width. Field Z lies approximately 35 km southeast of Kirkuk and runs parallel to Field Y and is located about 14 km away from it. It is characterized by an asymmetrical longitudinal fold with a length of about 33 km and a width of 4 km (Fig. 1). The aims of the study are to characterize the microfacies types and to interpret their depositional environments using petrographic analysis and established microfacies models. Moreover, to describe vertical contacts between each formation and its immediate overlying and underlying units to determine whether they are conformable or unconformable. As well as to trace lateral lithological variations across wells and fields to assess spatial facies continuity or abrupt transitions, and to investigate potential controls on observed thickness differences across the study area. Also, to investigate and assess the roles of tectonic activity and to relate it to environmental and paleogeographic setting. Lastly, to reconstruct the paleo-shoreline position to predict the distribution

of potential reservoir facies such as grain-dominated and reefal carbonates.

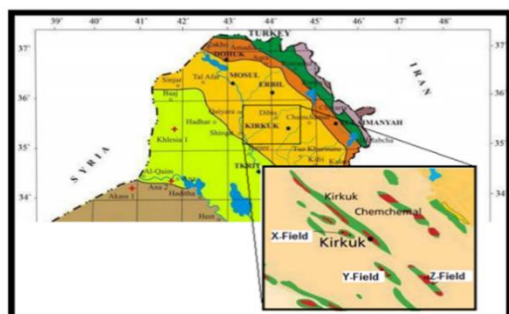


Fig. 1: Location map of the study area (modified from Fouad, 2010)

3. Geological Setting

The Anah, Azkand and Ibrahim formations, along with the Kirkuk Group, are assigned to the Oligocene depositional sequence (Bellen et al., 1959). The paleogeography and depositional history of the Oligocene follow quite closely the pattern set in Middle–Upper Eocene time. The northeastern margin of the depositional area lay much to the southwest of the position of the corresponding boundary of the Middle–Upper Eocene stages. Upper Oligocene sediments were deposited after regression and have a much smaller areal distribution than those of the Lower and Middle Oligocene (Dunnington, 2005). The Oligocene sediments in Iraq have a relatively restricted area of distribution and are reduced in thickness too. The underlying and overlying contact formations of the Oligocene are separated by a break and unconformity. A characteristic feature of the Oligocene is the absence of the molasse sediments in the foredeep (Buday, 1980). This sequence has commenced at the end of the Eocene, coinciding with tectonic adjustments that narrowed the main intraplate basin. These adjustments were driven by the westward tilting of the Arabian Plate and the uplift of the High Folded Zone during this period. The western shoreline migrated eastward toward the present-day Euphrates River, while the eastern shoreline retreated to the southwestern margin of the Butmah–Chemchemal Subzone within the Foothill Zone. The Neo-Tethys Ocean had become a narrow seaway, characterized by mixed siliciclastic and carbonate deposition. The Oligocene basin extended across several structural zones, including the Mesopotamian Zone,

Makhul–Hemrin Subzone, Jazira Subzone, and the northern margin of the Rutba Subzone. Notably, areas such as the Salman Zone and parts of the Euphrates and Zubair subzones underwent uplift during this period. As shown in Fig. 2, the basin was relatively narrow, with thick fringing reefs developing along both the western and eastern margins. In contrast, the central part of the basin was dominated by thin marly deposits (Jassim and Goff, 2006).

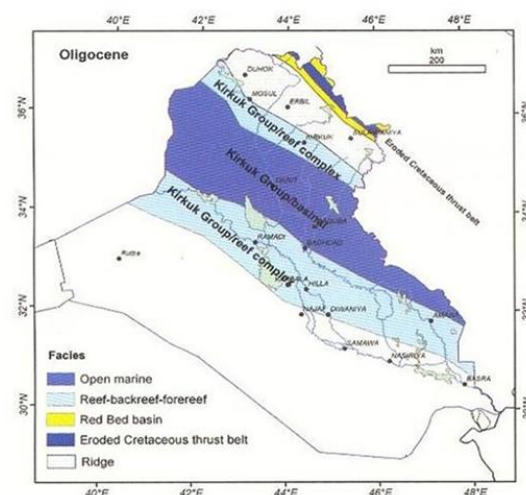


Fig. 2: Oligocene paleogeography (Jassim and Goff, 2006).

4. Methodology

Data (geological studies, logs, cores, cuttings, final well reports, and well file reports) are gathered for the four oil wells that have the most thin sections: two from the X oilfield and one from each of Y and Z.

Using a petrographic microscope, the lithology of the Ibrahim, Azkand, and Anah formations in wells X1 and X2 from field X, well Y from field Y, and well Z from field Z is determined using rock cutting samples accessible at the Geology Department, North Oil Company.

More than 250 thin sections of core and cuttings are used in petrographic analysis from the chosen wells. The description is achieved in the Geological Department Laboratory of Iraqi North Oil Company using a transmitted light microscope. The petrographic and textural properties are based on Dunham's (1962) classification.

The both Software's, Petrel 16 and Golden Grapher 16, are utilized in order to draw column stratigraphy, well correlation, and a paleo-depositional environment model for the studied formations.

Finally, a comparison between well log readings and microfacies analysis is conducted to enhance the accuracy of facies analysis in identifying the depositional environments.

5. Results and Discussion

The transition into the Early Miocene was marked by the Savian tectonic movement, which significantly affected the Zagros suture zone. This event is distinguished by the uplift of the Balambo–Tanjero trough (Abdulrahman and Awadh, 2021). The Oligocene stratigraphy is subdivided into nine formations grouped into three sequences interpreted as Early, Middle and Late Oligocene based on relative stratigraphic position rather than fossil evidence. These sequences exhibit lateral facies transitions from basinal to reef and back-reef environments (Bellen et al., 1959). Anah, Azkand and Ibrahim formations age back to the Late Oligocene to Early Miocene epochs as confirmed by Abid (1997); Ghafor and Ahmad (2019) and Abdulrahman and Awadh (2021) through detailed stratigraphic and lithological analysis.

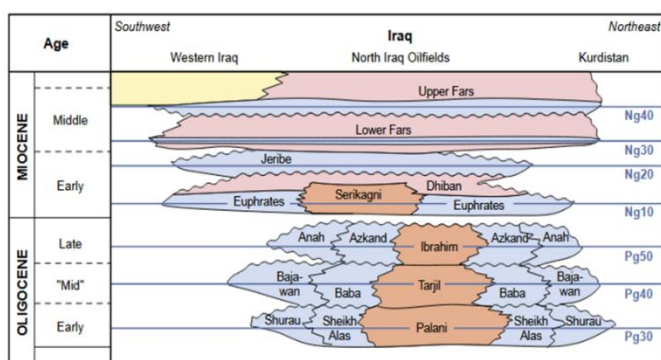


Fig. 3: Sequence stratigraphy of the mid-Miocene to Oligocene of Iraq after Sharland et al. (2004).

5.1. Lithostratigraphy

The Ibrahim Formation was initially characterized by Bellen et al. (1959) in the Ibrahim-1 well. It primarily consists of clayey limestone with glauconite and pyrite, and its lower and upper boundaries are unconformable with the Jaddala and Fatha formations respectively. In the present study, it appears that the Ibrahim Formation comprises partially dolomitized and recrystallized limestone interbedded with light brown marly limestone bands particularly in its lower parts.

According to NOC (2013) and based on the study result, the formation's thickness varied

significantly across the study fields: approximately 50 meters in Field X, about 20 meters in Field Y, and 213 meters in Field Z. In both Fields X and Z, the upper boundary of the Ibrahim Formation is conformable with the Azkand Formation, whereas its lower contact is unconformable with the Tarjil Formation, but in Field Y, the lower boundary of the formation is unconformable with the underlying Tarjil Formation, while its upper boundary is conformable with the overlying basal anhydrite layer (NOC, 1988).

The type locality of the Azkand Formation is situated approximately 5 km northeast of Azkand village on the southern dome of the Qarah Chauq structure. It was first described by Bellen (1956, cited in Bellen et al., 1959) as dolomitic limestone with high porosity and interpreted to have been deposited in a fore-reef environment.

Based on the cutting description, gamma ray, sonic and FD-CNL logs with final well reports, it appears that the Formation consists of porous and oil-saturated dolomitic rocks with a coarse-grained, brown-colored texture and substantial porosity. These rocks interfinger with white and fractured limestone units. It is characterized by the presence of coral reef fragments in its middle sections and anhydrite nodules in its lower parts. The thickness of the formation is approximately 70 meters in Field X and up to 120 meters in Field Z, whereas the formation was not encountered in Field Y. In Fields X and Z, the formation is conformably bounded by the underlying Ibrahim Formation and the overlying Anah Formation.

The type locality of Anah Formation is located 15 km east of Nahiya, along the western bank of the Euphrates River. It was initially described by Bellen (1956, referenced in Bellen et al., 1959) as grey and coralline limestone interpreted to have been deposited in a back-reef setting. In its type section, the lower boundary is conformable with the underlying Azkand Formation, while the upper contact is marked by an unconformity with the overlying Euphrates Formation (Al-Sayyab and Al-Hamdani, 1990). The Anah Formation is described as consisting of massive and recrystallized limestone. Specifically, it comprises white and fine-crystalline porcelain limestone interbedded with dolomitic limestone rocks exhibiting a fine to medium texture. The formation's thickness reaches 10 meters in well Z1 and ranges between 16 and 19 meters in the wells of Field X. The Anah Formation is absent in Field

Y. In Field X, the base of the formation is in conformable contact with the underlying Azkand Formation, whereas the upper boundary is marked by a distinct unconformity beneath the Jeribe Formation. In Field Z, the Azkand Formation conforms to the Anah Formation lower limit, but they do not conform at the top boundary with the Euphrates Formation.

5.2. Microfacies Analyses

Microfacies analysis of carbonate rocks is implemented for understanding basin evolution and stratigraphic correlations (Scholle and Ulmer-Scholle, 2003). It is a detailed description and interpretation serve to infer depositional environments and interpret sedimentary depositional processes and diagenetic histories (Flügel and Munnecke, 2010; Tucker, 2011). Microfacies analysis involves the determination of microscopic lithofacies, which are defined previously by distinct assemblages of constituents (grains, textural attributes, and diagenetic alterations) identified through thin-section examination. The classification system of Dunham (1962), with its modifications by Embry and Klován (1971) was applied in order to determine the depositional environments (physical, chemical and biological conditions under which sediments were deposited like shallow marine, reef, fluvial) for each formation within the study area. The identified facies (distinct rock units characterized by specific textures, compositions, and fossil content determined through petrographic analysis) are utilized and compared with the established standard facies models (Wilson, 1975; and Flügel, 2010).

5.2.1 Microfacies Analysis of Ibrahim Formation

1- Planktonic Foraminiferal Wackestone Microfacies (Ib1).

These facies are identified in the lower and middle parts of the Ibrahim Formation in the X and Z fields, whereas it constitutes the entire section of the formation in the Y field. The skeletal grains in these facies account 10-40% of its components and include the following planktonic foraminiferal genera: Globigerina, Globigerinoides, and Globorotalia. Additionally, the facies contain a minor proportion of benthic foraminifera such as Lepidocyclus, Ammonia, Textularia sp., and

Rotalia, along with scattered echinoderm fragments. The matrix varies between microcrystalline (micrite) in some intervals and fine sparite cement in others and some non-carbonate particles such as pyrite and rare glauconite. These facies have undergone diagenetic alterations, including dissolution, which has resulted in locally developed moldic porosity, as well as neomorphism that transformed some grains into a xenotopic fabric in certain areas. The intergranular pores are predominantly filled by drusy calcite cement, which also precipitated within some of the chambers of the planktonic foraminifera; fracture porosity filled with calcite is observed, particularly in sections from the Y field. The presence of benthic foraminifera reflects a warm temperate environment with water temperatures ranging between 14–26 °C (Murray, cited in. Rahman, 2007). This facies corresponds to the standard facies SMF-3 forams, and it falls within the deeper parts of the FZ-3 biofacies zone according to Wilson (1975) and Flügel (2010), indicating a Deep shelf - toe-of-slope depositional environment (Plate A: 1, 3, 4, 5, 6, 7, 8, 9).

2- Microbreccia, Bio-Lithoclastic Packstone Microfacies (Ib2).

This facies represents the upper part of the Ibrahim Formation in the X and Z fields, characterized by a color range from brown to grayish. The skeletal grains constitute 40–60% of the total components in these facies, and it is composed of relatively small planktonic foraminifera, including various genera such as Globigerina, Globigerinoides, and Globorotalia. These taxa are commonly associated with open marine, mid- to outer-shelf environments (Perch-Nielsen et al., 1985). In addition, the facies contain fine-grained breccias, debrites, and lithoclast grains with bioclasts including fragments of red algae, echinoderms, Ammonia and Rotalia.

Lepidocyclus indicate a mixed biogenic input derived from both shallow-water and deeper marine environments. The matrix is primarily composed of micrite and fine sparite with minor amounts of quartz and silt-sized siliciclastic grains, suggesting limited terrigenous influence within the carbonate depositional system. These facies have undergone significant diagenetic modifications, particularly dolomitization, which is evident from the presence of fine-crystalline dolomite and micro-sucrose textures. Some dolomite rhombs

appear subhedral to euhedral. Additionally, dissolution processes have resulted in vuggy porosity, partially filled by anhydrite or calcite cements of localized post-depositional origin. Locally developed pyrite and minor glauconite are also present, indicating episodes of reducing conditions during early diagenesis. According to Schlager (2005), turbidites or debris-flow deposits are typically found in the toe-of-slope setting, representing reworked mixtures of shallow-water bioclasts and deeper marine benthic and planktonic sediments. Based on the above observations, this facies closely resembles the standard facies MFS-4, which belongs to facies zone FZ-3 as defined by Wilson (1975) and Flügel (2010), commonly associated with the Deep shelf - toe-of-slope environment in a carbonate platform system (Plate A: 10, 11, 12).

5.2.2 Microfacies Analysis of Azkand Formation.

1- Larger foraminifera lime Packstone microfacies (Az1)

These facies are observed in the lower part of the Azkand Formation in the X and Z fields. Skeletal grains constitute approximately 50% of the facies components and are represented by large foraminiferal genera such as *Lepidocyclina*, *Amphistegina*, *Operculina*, and *Miogypsinoidea*. In addition, red algae, echinoderm fragments and mollusks are identified. The matrix consists of fine spar and sparry calcite with the presence of pyrite grains within the matrix. The facies have been affected by diagenetic processes such as dolomitization, moldic porosity development, and micritization. Several types of porosity are recognized, including moldic porosity, intraparticle porosity, and vuggy porosity. The presence of large benthic foraminifera such as *Miogypsina* sp., coralline algae, other bioclasts, and skeletal echinoderms suggests a moderate- to high-energy depositional environment located on the upper part of a carbonate platform slope, at water depths less than 50 meters, under moderate salinity conditions (Geel, 2000), in these facies corresponding to the standard Wilson (1975) and Flügel (2010) SMF-5 facies in the FZ-4 slope environment. This interpretation is also consistent with the findings of Reijmer (2021) (Plate B: 9, 10, 11, 12).

2- Lime coral bindstone-framestone lithofacies (Az2).

This microfacies represents the upper part of the Azkand Formation in the X and Z fields, which consists mainly of the massive coral genus *Colpophyllia* along with various algal species, and it includes some benthic foraminifera such as *Rotalia* and *Amphistegina* along with some mollusks and echinoderm fragments. The rock debris includes *Corallina* bioclasts. These facies have been affected by dolomitization, recrystallization, and chemical compaction (pressure solution). Porosity of various types has been observed, in addition to the presence of cement. The faunal diversity and presence of algae indicate a shallow and warm marine environment according to Reading (2009). Moreover, the occurrence of the genera *Amphistegina* and *Operculina* (Plate B: 2,5) suggests a reef environment of moderate to low energy conditions (Boudaughier-Fadel, 2018). Furthermore, this interpretation aligns with the findings of Pomar et al. (1996).

Accordingly, and based on the classifications of Wilson (1975) and Flügel (2010), this faunal assemblage corresponds to the standard microfacies SMF-7 within the Reef biofacies zone FZ-5 (Plate B: 1, 6, 7).

5.2.3 Microfacies Analysis of Anah Formation:

1- Fossiliferous Lime Wackestone microfacies (An1)

This facies occurs in the lower part of the Anah Formation within both the X and Z fields. It is characterized by a gray color and medium hardness. Skeletal grains constitute 10-40% of the total components in these facies. Fossils identified within these facies include *Austrolina*, *Archaias*, *Purgos*, *Miogypsinoidea*, and *Peneroplis*. In addition, red and green algal fragments, mollusk shells, and coral pieces are also present. The facies have undergone several diagenetic processes, including dolomitization, dissolution, and recrystallization. Moldic porosity is observed, indicating post-depositional leaching of skeletal components. According to Pomar et al. (1996) and Youssef et al. (2021), this facies represents an outer lagoon environment. Furthermore, it closely resembles the standard microfacies SMF-8; the presence of calcareous algae supports the attribution to the FZ-

7 zone representing an open marine interior platform environment as defined by Wilson (1975) and supported by Flügel (2010) (Plate A:13, 15 and Plate B: 3, 8, 14).

2- Benthic foraminifera lime Grainstone - Packstone microfacies (An2)

These facies occur in the middle and upper parts of the Anah Formation within the X Field, in the Z Field area. They interfinger with other facies constituting the formation throughout the section where the formation is exposed. The dominant skeletal components are benthic foraminifera, particularly Miliolid, Peneroplis, and Dendritina (Plate B: 13). The matrix consists of micrite and fine-crystalline spar. These facies have been affected by various diagenetic processes such as dolomitization, recrystallization, and cementation. Porosity is moderate and mainly intergranular in nature. According to Beavington-Penney and Racey (2004), Peneroplis are commonly found in shallow marine environments less than 30 meters deep. Additionally, Geel (2000) indicated that low diversity among miliolids and other benthic foraminifera suggests a very shallow, restricted, and possibly hypersaline environment, as cited in Al-Jwaini (2015) based on Pomar's classification (Pomar et al., 1996), which divides the back-reef lagoon into an inner zone close to the shore and an outer zone farther from the coast but closer to the reef tract environment. Furthermore, following Wilson (1975) and Flügel (2010), this facies closely resembles the standard microfacies SMF-18. The presence of abundant miliolids and foraminifera exhibiting tolerance to high-salinity conditions suggests deposition in a restricted and hypersaline environment. This interpretation aligns with the microfacies criteria of Flügel (2010) and supports the assignment of this facies to the FZ-8 zone, which represents a restricted platform interior setting (Plate A: 2, 14 and Plate B: 15).

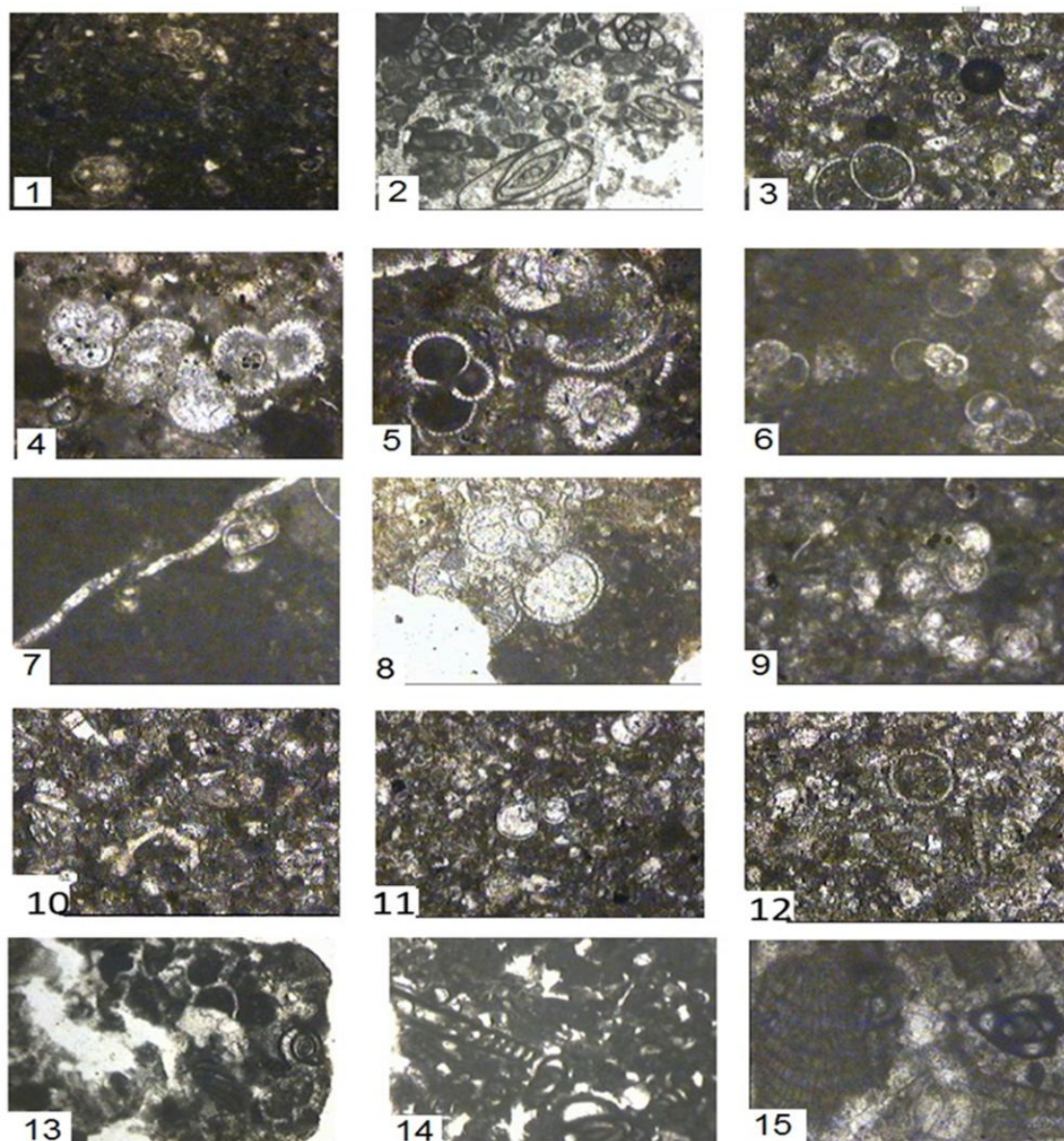


Plate A. 1: Planktonic Foraminiferal Wackstone Microfacies (Ib1), X2, 2346 m 2- *Miliolid* in Benthonic foraminifera lime Grainstone-Packstone microfacies (An2), X1, 2141m 3- Planktonic Foraminiferal Wackstone Microfacies (Ib1), X1, 2260 4- Planktonic Foraminiferal Wackstone Microfacies (Ib1), Y, 1966 m 5- *Globigerinidae Trilobites* in Planktonic Foraminiferal Wackstone Microfacies (Ib1), Y, 1966 m 6- *Globigerinid* in Planktonic Foraminiferal Wackstone Microfacies (Ib1), Y, 1983 m 7-Fracture in Planktonic Foraminiferal Wackstone Microfacies (Ib1), Y, 1983 m 8- *Globigerinoides subquadratus* in Planktonic Foraminiferal Wackstone Microfacies (Ib1), Z, 1884 m 9- *Catapsydrax dissimilis* in Planktonic Foraminiferal Wackstone Microfacies (Ib1), Z, 1887 m 10 Microbreccia, Bio-Lithoclastic Packstone Microfacies (Ib2), X1, 2240 m 11- Microbreccia, Bio-Lithoclastic Packstone Microfacies (Ib2), Z, 1780 m 12- Microbreccia, Bio-Lithoclastic Packstone Microfacies (Ib2), Z, 1776 m 13- Fossiliferous Lime Wackstone (An1), X2, 2220m 14- *Peneroplis* sp. in Benthonic foraminifera lime Grainstone-Packstone microfacies (An2), X2, 2212m 15- Red algae in - Fossiliferous Lime Wackstone (An1), X2, 2224 m. "All images were captured under a polarizing microscope at a magnification of 40x.

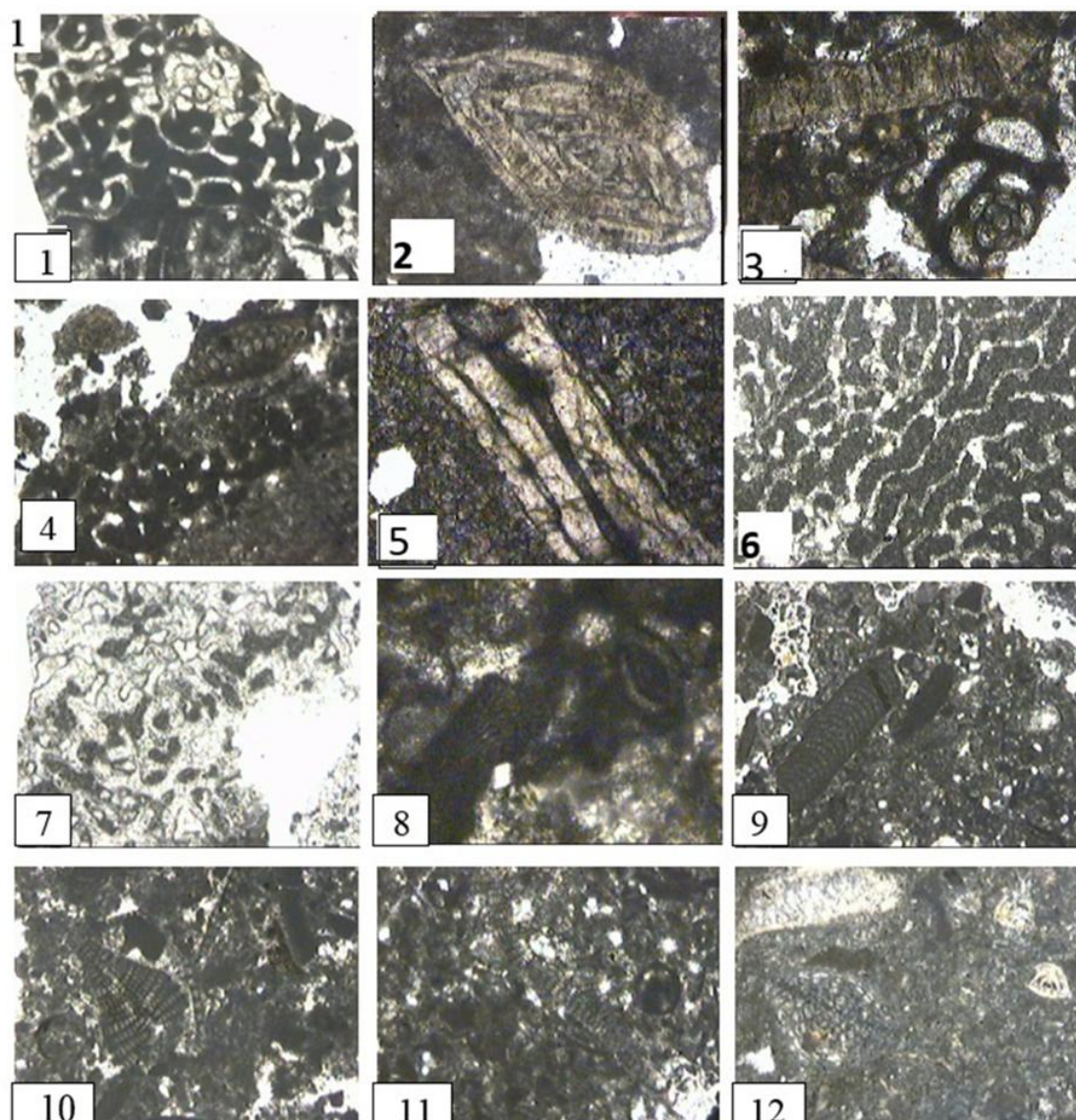


Plate B. 1: Lime coral bindston-framestone Lithofacies (Az2), X2, 2232m 2- Amphistegina, X1, 2175m 3- Austrolina, in Fossiliferous Lime Wackstone microfacies (An1), X1, 2141m 4-Miogysinoide X2, 2246m 5-Operculina, Z, 1668m 6- Lime coral bindston-framestone Lithofacies (Az2), X1, 2178m 7- Lime coral bindston-framestone Lithofacies (Az2), Z1, 1638m 8- Fossiliferous Lime Wackstone (An1), X1, 2150m 9—Red algae in Larger foraminifera lime Packstone microfacies (Az1), Z, 1724m 10—Lepidocyclina in Larger foraminifera lime Packstone microfacies (Az1), X2, 2288m 11- Lepidocyclina in Larger foraminifera lime Packstone microfacies (Az1), Z, 1728m 12- Lepidocyclina in Larger foraminifera lime Packstone microfacies (Az1), Z, 1746m 13- Dendritina, X2, 2212m 14- Fossiliferous Lime Wackstone (An1), Z, 1631m 15- - Benthonic foraminifera lime Grainstone-Packstone microfacies (An2), X1, 2136m."All images were captured under a polarizing microscope at a magnification of 40.

6. Paleoenvironment

The depositional environments of the Ibrahim, Azkand and Anah formations are interpreted through an integrated approach involving lithostratigraphic correlation, detailed facies analysis and the synthesis of electric log data from the examined wells (Fig. 4,5,6 and 7). The lower and middle parts of the Ibrahim Formation

were deposited in the deeper parts of zone FZ-3, representing a deep shelf to toe-of-slope depositional environment, whereas the upper part of the formation was deposited in the shallower parts of the same environment or zone (FZ-3). These vertical facies transition is consistent with the depositional model reported by Abdulrahman and Awadh (2021) for the same formation. Similarly, the lower section of the Azkand Formation was deposited within zone FZ-4, which

is interpreted as an upper-slope environment that evolved gradually upward into a reefal setting (FZ-5) before end of the formation. This conclusion is compatible with the models proposed by Mahdi et al. (2022) and Abood and Al-Zaidy (2024). The lower part of the Anah Formation was deposited within zone FZ-7, interpreted as a platform interior with normal marine conditions within an open marine platform, while the middle and upper sections of the formation were deposited in a restricted platform interior environment assigned to zone FZ-8. Also, this depositional pattern is coordinated with the facies models proposed by Ghafor and Ahmad (2019); Mahdi et al. (2022) and Abood and Al-Zaidy (2024), supporting a vertical transition from open to restricted marine conditions during the formation accumulation.

On the other side, a deep depositional environment is evidenced by the existence of clay-rich intervals (marl), which is confirmed by the discernible relative rise in gamma ray log values at the beginning of the Ibrahim Formation, followed by a slow shallowing upward, which is demonstrated by the consecutive decrease in both the amount of clay (marl) and gamma ray log values at the Azkand and Anah formations in all of the wells under study. A regressive depositional history is supported by the vertical variation trend in the lithology and log response.

The Ibrahim Formation is interpreted to have been deposited in a deep shelf-to-toe-of-slope environment representing a relatively deep and low-energy sector of the basin, followed by the Azkand Formation accumulated within upper slope to reef-margin settings. This is indicative of a shallower and higher-energy zone near the platform break. Finally, the Anah Formation reflects deposition in shallower inner-platform settings trending toward coastal depositional systems.

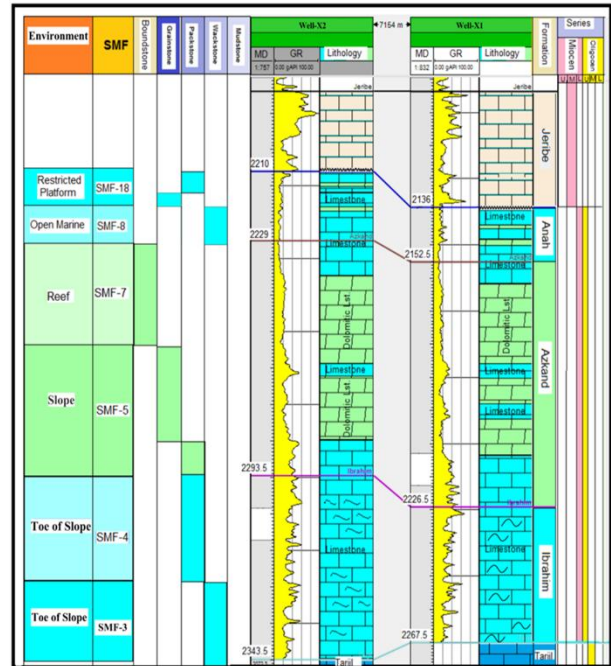


Fig. 4: Lithological column section showing microfacies and environment of studied succession in wells x1 and x2.

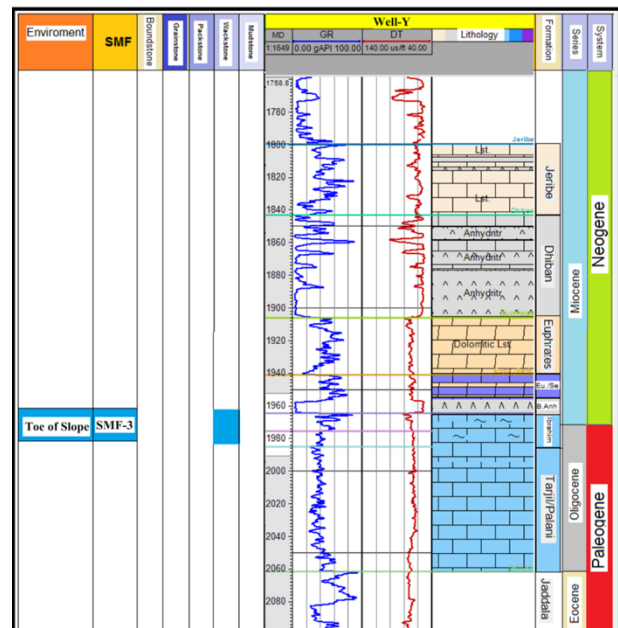


Fig. 5: Lithological column section showing microfiches and environment of studied succession in well Y.

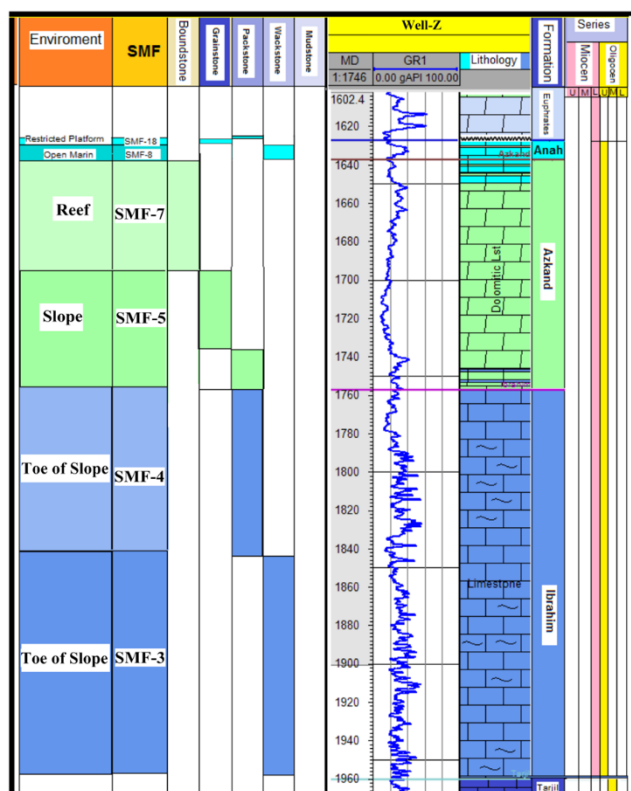


Fig. 6: Lithological column section showing microfiches and environment of the studied succession in well Z.

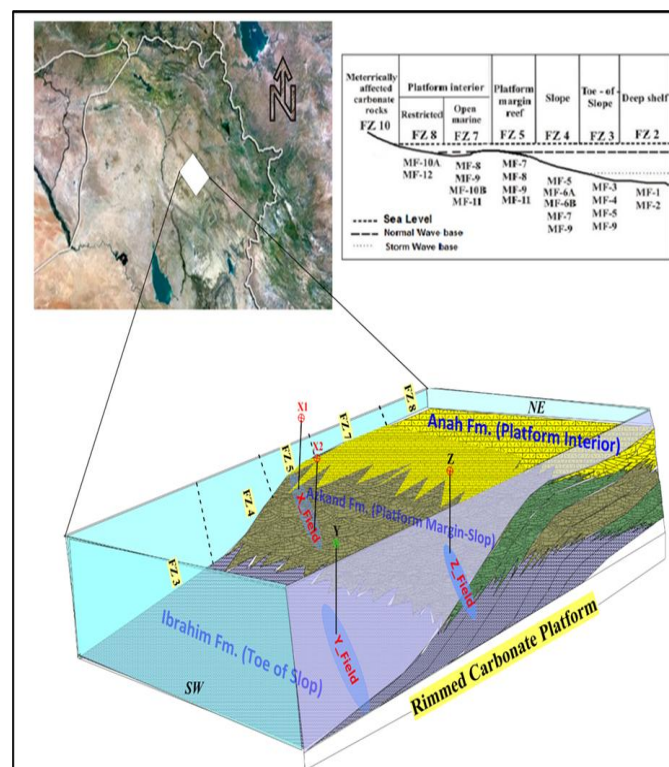


Fig.8: Rimmed carbonate platform model that describes the depositional setting of the Anah, Azkand, and Ibrahim Formations. According to Wilson (1975) and Flügel (2010).

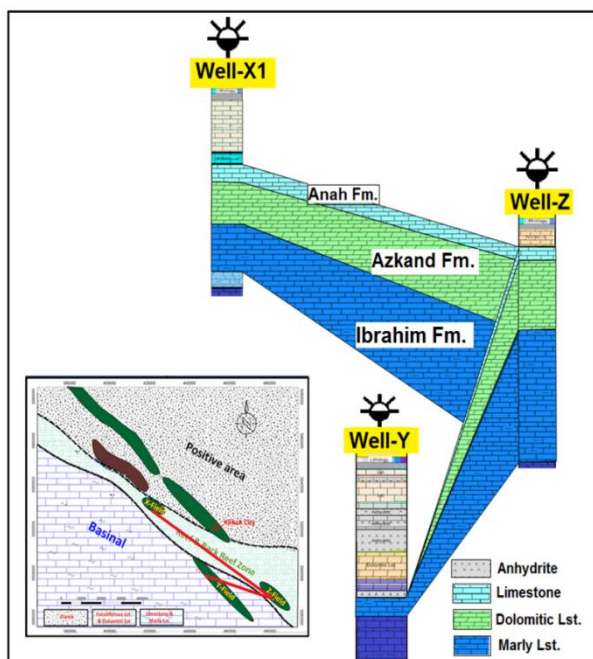


Fig.7: Lithology fence diagrams between X1, Y, and Z Wells in the study area.

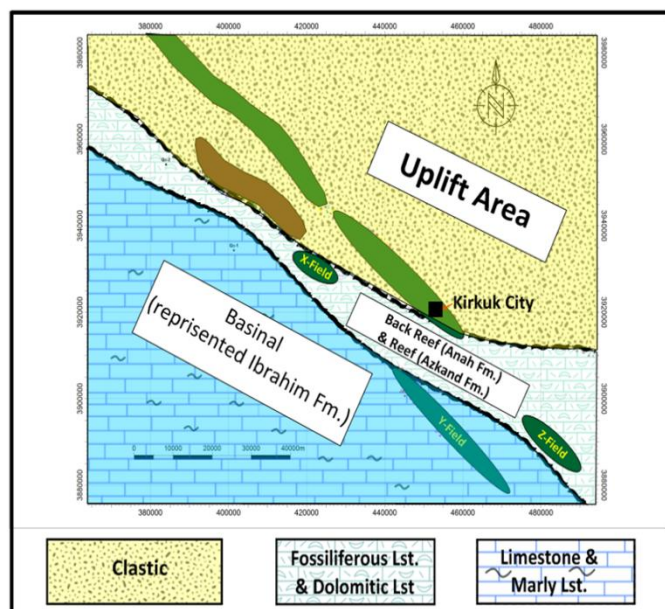


Fig. 9: Late Oligocene-Early Miocene paleo shoreline and the boundaries of the shallow and basinal facies in the study area (modified from Al-Eisa, 1992).

As shown in Fig. 8, which summarizes the reconstructed formations. According to Wilson (1975) and Flügel (2010). The Ibrahim Formation represents the distal margin of a rimmed carbonate platform. It was deposited in a deep-water and low-energy environment beyond the influence of normal wave action, where sediments were transported downslope via gravity-driven processes such as slumping and turbidity currents originating from the adjacent platform margin. This unit marks the outermost expression of the carbonate system, accumulating fine-grained carbonate debris and hemipelagic material in a setting characterized by limited bioturbation and episodic sedimentation. Overlying and laterally adjacent to the Ibrahim Formation, the Azkand Formation occurs exclusively within the platform margin reef and the upper part. It records deposition in a high-energy and shallow marine environment dominated by wave action, storm events, and reef growth. This zone represents the primary site of carbonate production, where framework-building organisms and skeletal debris accumulated rapidly, forming a prominent reef barrier that separated the platform interior from deeper waters. The Azkand Formation thus constitutes the structural and sedimentological keel of the platform system. Inland from the margin, the Anah Formation was deposited across the platform interior. It has been formed under low- to moderate-energy conditions in shallow and protected waters, where fine-grained carbonate sediments have accumulated with minimal reworking. This area experienced variable circulation ranging from semi-restricted lagoonal settings to more open marine conditions, supporting diverse benthic communities and promoting the development of mud-dominated deposits. Thus, the three formations were deposited contemporaneously along a lateral transect from the deep-water toe-of-slope (Ibrahim Formation) through the reef-rimmed margin (Azkand Formation) to the shallow platform interior (Anah Formation), reflecting a systematic environmental gradient controlled by water depth, hydrodynamic energy and proximity to the platform edge. This configuration illustrates a classic rimmed carbonate platform architecture, where lateral facies transitions record the interplay between carbonate production, wave energy and gravity-driven sediment transport during a single

depositional phase. This finding is consistent with the conclusions given by Mahdi et al. (2022). The model represents a discrete depositional episode within a rimmed carbonate platform system, which was subsequently followed by phases of marine regression. These regressions triggered the progradation of Azkand Formation sediments over those of the Ibrahim Formation, while simultaneously, Anah Formation sediments were deposited overlying the Azkand Formation. This vertical stacking pattern is clearly documented in the stratigraphic logs of the studied wells, reflecting a regressive and shallowing-upward succession, wherein platform-derived facies progressively overstepped deeper-water slope and toe-of-slope deposits in response to falling relative sea level.

Based on a comparison of the thicknesses of the studied formations Anah, Azkand and Ibrahim (Table 1), it is observed that well Z, located in Field Z, lies within the central part of the sedimentary basin. This finding aligns with the study of Abid (1997), which indicated that the Oligocene basin comprises three main sedimentary centers aligned along a northwest–southeast axis. The first center lies north of Mosul, the second corresponds to the Kirkuk Basin, where well Z represents its depositional core, while the third is the Amara Basin.

Table 1: Studied formations' thicknesses.

Well Name	Anah	Azkand	Ibrahim
X1	16 m	74 m	41 m
X2	19 m	64 m	50 m
Y1	0 m	0 m	20 m
Z1	10 m	120 m	213 m

The Anah Formation was deposited in a restricted back-reef setting, where the absence of a well-defined lagoonal facies suggests a limited hydrodynamic circulation. This overall retrogradation pattern, as evidenced by the landward shift in facies belts and the observed regressive trend across the three formations, is likely consistent with sustained tectonic uplift within the basin, which led to a decrease in accommodation space driven by regional uplift. Based on this interpretation, a paleoenvironmental depositional model for the basin is consistent with the findings reported by North Oil Company (1992) in their studies of X field (NOC, 1992). Variations in formation thickness indicate that the depocenter was located near Field Z, where the

cumulative thickness reaches approximately 350 m compared to about 130 m in Field X. This observation is consistent with the findings of Jassim and Goff (2006). Field Y is interpreted to lie within a deep basinal setting. Based on this thickness distribution and depositional architecture, the paleo-shoreline is inferred to have run roughly parallel to the line connecting Fields X and Z, trending northwest–southeast relative to Iraq, and positioned slightly north of Field Y (Fig. 8). The 80 km distance between Fields X and Z includes a 40 km segment that lacks distinct surface expressions of subsurface structures.

Despite the absence of clear surface features, this area is considered prospective for hydrocarbon exploration due to its favorable paleogeographic position within the evolving carbonate platform system.

7. Conclusion

The Ibrahim, Azkand and Anah formations were deposited within a rimmed carbonate platform depositional system during the late Oligocene to early Miocene in the Low Folded Zone of Iraq. Detailed microfacies analysis of the carbonate successions in the X, Y, and Z oil fields identified six principal microfacies types reflecting a spectrum of depositional environments along the platform margin.

- The lower and middle parts of the Ibrahim Formation are characterized by microfacies SMF-3 and SMF-4 deposited in a toe-of-slope setting within zone FZ-3. The upper part of the formation shows a shallowing-upward trend consistent with a transition to a shallower platform environment within the same zone.
- The Azkand Formation exhibits microfacies SMF-5 in its lower section indicative of an upper slope environment (FZ-4), while its upper part is dominated by SMF-7 representing a reef setting within zone FZ-5.
- The Anah Formation with microfacies SMF-8 is interpreted as an open marine and platform interior environment (FZ-7), whereas SMF-18 in the middle and upper sections reflects a restricted platform interior setting (FZ-8).
- The vertical succession of microfacies supported by gamma ray log trends demonstrates a regressive and upward-shoaling pattern across all studied wells. The paleo-shoreline is inferred to have extended in a

northwest–southeast direction passing through fields X and Z and lying slightly north of field Y.

- The significant thickening of the formations near field Z, reaching up to approximately 350 meters compared to ~130 meters in field X, indicates that the depocenter of the basin was located in the vicinity of field Z.

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9. Conflict of Interest

The authors declare that they have no conflict of interest.

10. Funding Statement

Research received no external funding.

11. Author Contributions

Abdulla Ahmed Abid: Conceptualization; Writing – original draft; Investigation; Formal analysis; Visualization; Data curation. Developed the overall concept and design of the manuscript, prepared the research paper, participated in sample collection with the other authors, analyzed the data, and prepared the figures and tables.

Faris Nejres Hassan Al Jubory: Conceptualization; Supervision; Project administration; Writing – review and editing. Contributed to the development of the research ideas and writing approach, supervised the research and data-collection process, and conducted a comprehensive critical review and revision of the manuscript.

Saad Ahmed Mahmood: Investigation; Formal analysis. Contributed to sample collection and analysis of the resulting data.

Note: The contribution categories are aligned with the CRediT (Contributor Roles Taxonomy) framework, where applicable.

12. References

Abdulrahman, A. and Awadh, S.M., 2021. Depositional environment of the Ibrahim Formation and determining the Oligocene-Early Miocene boundary in Eastern Iraq,

The Iraqi Geological Journal, Vol. 54, No. 2E, pp. 85–97. <https://doi.org/10.46717/igi.54.1F.8ms-2021-06-28>

Abid, A., 1997. Biostratigraphy and Microfacies of the Late Oligocene–Middle Miocene formations, Center and North Iraq, Unpublished Ph.D. Thesis, University of Baghdad, 240 P. (In Arabic)

Abood, M.S. and Al-Zaidy, A.A., 2024. Depositional Environment and Stratigraphic Sequence of the Oligocene Succession in Fallujah and Melh-Tharthar Oilfields, Central Iraq, The Iraqi Geological Journal, Vol. 57, No. 1C, pp. 168–183. <https://doi.org/10.46717/igi.57.2F.11ms-2024-12-21>

Al-Eisa, M.E.S., 1992. Coral reef of Late Oligocene - Early - Miocene Kirkuk and surrounding areas.: Iraqi Geol. Jour., Vol. 25, No.2, pp.17-32.

Al-Hashimi, H. and Amer, R., 1986. Restudy of the Ibrahim Formation in the type section, Ibrahim Well No. 1, Mosul area, N. Iraq, Journal of the Geological Society of Iraq, Vol. 19, No. 3, pp. 93–100.

Al-Jwaini, Y.S.K., 2015. Sequence stratigraphy and reservoir characterization of the late Paleogene–early Neogene succession in Kirkuk area, Unpublished M.Sc. Thesis, University of Baghdad, Iraq, 142 P. (In Arabic)

Al-Sayyab, A.S. and Al-Hamdani, A.T., 1990. Biostratigraphy of the Anah and Euphrates Formations at Wadi Banat Al-Hassan (W. Iraq), Bulletin of the Iraqi Natural History Museum, Vol. 8, No. 3, pp. 61–83.

Al-Shareeda, W.M., Al-Abbasi, M.W., Al-Hamidi, R.I., and Malak, Z.A., 2025. Paleoenvironment and Petrophysical Properties of Bajwan Formation at Kirkuk Oil Field, Northeastern Iraq, Unpublished Report.

Beavington-Penney, S. J. and Racey, A., 2004. Ecology of extant nummulitids and other larger benthic foraminifera: applications in paleoenvironmental analysis, Earth-Science Reviews, Vol. 67, No. 3–4, pp. 219–265.

Bellen, R. V., Dunnigton, H., Wetzel, R., and Morton, D., 1959. Lexique stratigraphique international: Asie, fascicule 10a, Iraq, Centre National de la Recherche Scientifique, Paris, Vol. III, 333 pages.

Boudaughier-Fadel, M.K., 2018. Evolution and geological significance of larger benthic foraminifera, UCL Press, 450 P.

Buday, T., 1980. The Regional Geology of Iraq, Volume I: Stratigraphy and Paleogeography. Directorate General of Geological Survey and Mineral Investigation, Baghdad, Iraq. 445 P.

Ditmar, V., 1971. Geological Conditions and Hydrocarbon Prospects of the Republic of Iraq (Northern and Central Parts), 120 P. (Unpublished)

Dunham, R.J., 1962. Classification of carbonate rocks according to depositional texture, in Ham, W. E. (Ed.), Classification of Carbonate Rocks, AAPG Memoir, Vol. 1, pp. 108–121.

Dunnigton, H.V., 2005. Stratigraphic Lexicon of Iraq. Ministry of Oil, State Organization for Oil Projects, Baghdad, Iraq. 404 P.

Embry, A.F. and Klovan, J.E., 1971. A late Devonian reef tract on northeastern Banks Island, NWT, Bulletin of Canadian Petroleum Geology, Vol. 19, No. 4, pp. 730–781.

Flügel, E., 2010. Microfacies of Carbonate Rocks, Springer, Analysis, Interpretation and Application, 2nd Edition, 984 P. <https://doi.org/10.1007/978-3-642-03796-2>

Fouad, S.F., 2010. Tectonic and structural evolution of the Mesopotamia Foredeep, Iraq, Iraqi Bulletin of Geology and Mining, Vol. 6, No. 2, pp. 41–53.

Geel, T., 2000. Recognition of stratigraphic sequences in carbonate platform and slope deposits: empirical models based on microfacies analysis of Paleogene deposits in southeastern Spain, Palaeogeography, Palaeoclimatology, Palaeoecology, Vol. 155, No. 3–4, pp. 211–238.

Ghafor, I., Ahmad, P., and Khafaf, A.A., 2023. Biostratigraphy and paleoecology of the Anah Formation in Kurdistan Region, Iraq, Iraqi Bulletin of Geology and Mining, Vol. 19, No. 1, pp. 17–28. <https://doi.org/10.59150/ibgm1901a02>

Ghafor, I.M. and Ahmad, P.M., 2019. Biostratigraphy and paleoecology of the Anah Formation (Upper Oligocene) in the Sangaw area, Sulaimania Governorate, Kurdistan Region, NE Iraq, Iraqi Bulletin of Geology and Mining, Vol. 15, No. 2, pp. 1–15.

Karim K.H., Khanaqa, P.A., Ismail K.M. and Sissakian, V.K., 2012. Facies analysis of the Oligocene succession in Sharwaldir anticline, NE of the Kalar Town, NE Iraq. Iraqi Bull. Geol. Min., Vol. 8, No. 2, pp. 1-19.

Ighwan, T.A.R. and Al-Rahman, N.A.R.A., 2009. Stratigraphic Succession for (Aquitania–Lower Early Langhian) Stage in Well Kor Mor / 3 at Kirkuk Area, Iraqi National Journal of Earth Science, Vol. 9, No. 1, pp. 1–14. <https://doi.org/10.33899/earth.2009.40566>

Jassim, S.Z. and Goff, J.C., 2006. Geology of Iraq, Dolin, s.r.o., distributed by Geological Society of London, 341 P.

Lawa, F.A. and Ghafur, A., 2015. Sequence stratigraphy and biostratigraphy of the prolific late Eocene, Oligocene and early Miocene carbonates from Zagros fold-thrust belt in Kurdistan region. Arabian Journal of Geosciences, Vol.8, No.10, pp. 8143 – 8174.

Mahdi, H.A.A.R., Al-Kubaisi, M.S. and Al-Jawad, S. N., 2022. Microfacies Analysis and Diagenetic Assessment of the Late Oligocene–Early Miocene Succession in Khabaz Oilfield, Northern Iraq, The Iraqi Geological Journal, Vol. 55, No. 2C, pp. 85–104. <https://doi.org/10.46717/igi.55.1D.6Ms-2022-04-22>

Majeed, H., Alaws, M.D. and Al-Zaidy, A.A., 2025. Depositional Settings and Diagenetic Features of the Oligocene Sequence in the Kirkuk and Khabaz Oilfields, Northern Part of Iraq, The Iraqi Geological Journal, Vol. 58, No. 1C, pp. 57–74. <https://doi.org/10.46717/igi.58.1A.5ms-2025-1-15>

Mohammed, A.A. and Aljibouri, A.S., 2023. Microfacies Analysis and Depositional Environment of Upper Oligocene–Lower Miocene Succession in Wadi

Al-Khazgah of Anbar Governorate, Western Iraq, The Iraqi Geological Journal, Vol. 56, No. 2B, pp. 127–137. <https://doi.org/10.46717/igi.56.2D.10ms-2023-10-16>

NOC, 1988. Geological Study for Tertiary Reservoir in Jambur Oil Field, Unpublished Report.

NOC, 1992. Geological Study of Tertiary Reservoirs in Khabaz Field, Unpublished Report.

NOC, 2013. Geological and Petrophysical Study for Tertiary Reservoirs in Khabaz Field, Unpublished Report.

Perch-Nielsen, K., Saunders, J.B. and Bolli, H.M., 1985. Plankton Stratigraphy, Cambridge University Press, 925 P.

Pomar, L., Ward, W.C. and Green, D.G., 1996. Upper Miocene reef complex of the Lluçmajor area, Mallorca, Spain, Field Trip Guidebook, SEPM, 85 P. (Unpublished)

Rahman, N.A.R.A., 2007. Sedimentological and Petrophysical Properties study of Stratigraphic Succession for (Aquitania–Lower Early Langhian) Stage in Well Kor Mor / 3 at Kirkuk Area, Unpublished M.Sc. Thesis, University of Baghdad, 135 P. (In Arabic)

Reading, H.G., 2009. Sedimentary Environments: Processes, Facies and Stratigraphy, John Wiley and Sons, 552 P.

Reijmer, J.J., 2021. Marine carbonate factories: review and update, Sedimentology, Vol. 68, No. 5, pp. 1729–1796. <https://doi.org/10.1111/sed.12878>

Schlager, W., 2005. Carbonate Sedimentology and Sequence Stratigraphy, SEPM Concepts in Sedimentology and Paleontology, No. 8, 210 P.

Scholle, P.A. and Ulmer-Scholle, D.S., 2003. A Color Guide to the Petrography of Carbonate Rocks: Grains, Textures, Porosity, Diagenesis, AAPG Memoir, No. 77, 474 P.

Sharland, P.R., Casey, D.M., Davies, R.B., Simmons, M.D. and Sutcliffe, O.E., 2004. Arabian plate sequence stratigraphy – Revisions to SP2. Iraqi Bulletin of Geology and Mining style, GeoArabia, vol. 9, no. 1, pp. 199–214.

Tucker, M. E., 2011. Sedimentary Rocks in the Field: A Practical Guide, 4th Edition, John Wiley and Sons, 288 pages.

Wilson, J.L., 1975. The stratigraphy of carbonate deposits, in Carbonate Facies in Geologic History, Springer, pp. 20–55. https://doi.org/10.1007/978-1-4612-6383-8_2

Youssef, M., El-Sorogy, A., Al-Kahtany, K. and Saleh, M., 2021. Benthic foraminifera as bio-indicators of coastal marine environmental contamination in the Red Sea–Gulf of Aqaba, Saudi Arabia, Bulletin of Environmental Contamination and Toxicology, Vol. 106, No. 6, pp. 1033–1043. <https://doi.org/10.1007/s00128-021-03192-w>



تحليل السحنات الدقيقة والبيئات الرسوبية لتكوينات إبراهيم وازقند وعنه في حقول نفطية

مختارة من شمالي العراق

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الملخص

تركز هذه الدراسة على تحليل تكوينات إبراهيم وازقند وعنه في الحقول النفطية X و Y و Z بمنطقة الطيات الواقعة في العراق. كشف التحليل التكاملي للسحنات الدقيقة والتتابع الطبقي عن تتابع ترسيبي تراجع من الأوليغوسين المتأخر إلى الميوسين المبكر. يتميز الجزء السفلي والأوسط من تكوين إبراهيم بالسحنة SMF-3، التي ترسبت في بيئة سفح المنحدر (FZ-3)، وتنعكس ظروفًا منخفضة الطاقة. أما الجزء العلوي، فتتميز عليه السحنة SMF-4، مما يدل على تضحل نحو منصة أقل عمقًا، مُعلنًا بداية التراجع البحري. يُظهر تكوين ازقند استمرار تقدم المنصة الكربوناته؛ حيث يمثل جزؤه السفلي بالسحنة SMF-5 (أعلى المنحدر، FZ-4)، في حين يُميز الجزء العلوي السحنة SMF-7 (بيئة شعاب عالية الطاقة، FZ-5). أما تكوين عنه، فيبدأ بالسحنة SMF-8 (المنصة المفتوحة، FZ-7)، ثم يتطور عموديًا إلى السحنة SMF-18 (المنصة المقيدة، FZ-8). يدعم هذا التتابع التراجعي تسجيلات أشعة جاما التي تُظهر انخفاضًا تدريجيًا في النشاط الإشعاعي مؤكدة اتجاه التضحل التصاعدي. يقع مركز الحوض قرب حقل Z، بينما يحتل حقل Y موقعًا حوضيًا. ويمتد خط الساحل القديم باتجاه شمال غرب-جنوب شرق عبر العراق مرورًا بحقلي X و Z ومشكلاً منصة كربوناته ذات حواف (rimmed carbonate platform)، وهو ما له دلالات مهمة في توصيف الأماكن النفطية والتوجهات الاستكشافية.

الكلمات المفتاحية:

بيئة الترسيب، السحنات الدقيقة، أوليغوسين، مجموعة كركوك، العراق.

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